A SYSTEMS APPROACH TO THE DYNAMICS OF SPRUCE BUDWORM IN NEW BRUNSWICK

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A primary problem in ecological systems analysis is to insure communication between the ecologist and his technical assistant, the modeller. Our approach to this problem is through short intensive workshops involving ecological and modelling teams. This paper describes a model that was developed in such a workshop of the spruce budworm in New Brunswick. Though the model as yet lacks predictive power, it appears to have been valuable in helping to organize and redirect budworm research by Environment Canada.

INTRODUCTION

A variety of systems analysis methods are becoming increasingly popular in ecological research and management. Particularly in the area of dynamic models, most large research teams can now claim to have at least one tame mathematician or "modeller", whose ostensible purpose is the "synthesis" of a wide variety of data into some overall picture that it is hoped will capture the fancy of the ecological manager. The life histories of such modellers have usually followed the same basic pattern. An initial period of great enthusiasm is followed by a period of depression when the modeller learns that ecological systems are complex, the data are full of holes, no-one really understands what the modeller is doing, and no-one takes his initial results seriously. The depression period is usually followed by one of guarded enthusiasm when the modeller realizes that although his product lacks predictive power, it can provide a useful service by helping to clarify data needs (in the words of Holling (1972), "to help ask better questions"). At this point the modeller's difficulties really begin, because he must convincingly communicate his recommendations to biologists who by this time are quite unlikely to be sympathetic (Benyon, 1972).

In an effort to break this pattern and place mathematical modelling in reasonable perspective as a tool for clarification and communication leading only eventually to predictive power, we have been experimenting with workshops involving short periods (3-5 days) of intense interaction between research and modelling teams. The spruce budworm research group based in Fredericton, N. B., was one test case for the workshop approach; this paper discusses the model and research impacts that resulted from the budworm experiment.

THE WORKSHOP APPROACH

The workshop format that we have followed is described in detail elsewhere (Walters, 1974). Briefly, the idea is to divide a problem (e.g. New Brunswick budworm dynamics) into a series of well defined components or potential submodels, each of which can be attacked by a small group (2-4) of scientists and a modeller. The scientists are warned explicitly that the modeller can act only as a technician to translate their concepts and data into quantitative form. Each step in the translation process is worked out carefully within the small group, to insure that the scientists' ideas are faithfully represented and that they understand the limitations and assumptions of the quantitative representation. The submodels produced by the groups are

then coupled together into the overall dynamic model, which may be exceedingly complex
and not fully understood by any single scientist or modeller.

COMPONENTS OF THE BUDWORM MODEL

For the spruce budworm workshop we used the following four submodelling groups, each
with two or three scientists:
  (1) Population dynamics in single forest areas as a function of weather, forest stand con-
      ditions, and input of adult moths through dispersal.
  (2) Forest area dynamics (growth and species composition) as a function of budworm pop-
      ulation levels.
  (3) Adult dispersal between areas as a function of population levels, weather, and forest
      stand condition.
  (4) Management activities that could modify the dynamics modelled in groups (1) - (3)
      through changed forest condition or insecticide spraying.
Thus we did not consider all possible management options, and we did not attempt to include
any economic factors or calculations. Interrelationships between these submodels for the final
simulation are shown in Figure 1. For a detailed description of the model, see Stander (1973).

For representation of spatial effects, we decided to divide the province of New Brunswick
into 265 areas of 6 X 9 mi (Fig. 2) each of which would be treated as a relatively homogen-
eous area with regard to budworm dynamics. This pattern was chosen for convenience, since
it corresponds to forest inventory maps that were available during the workshop. The popu-
lation dynamics and forest area dynamics submodels were developed with this spatial repre-
sentation in mind, to insure that their functional relationships would be stated generally enough
so as to apply in all spatial areas.

The workshop participants decided that a detailed population dynamics model would not
be worthwhile, and that the essential features of local population change could be represented
with the simple set of functional relationships shown in Figures 3-4. For each area in any
simulated year, the model begins with egg density and simulated weather pattern (poor, aver-
age, or good, based on temperature and rainfall). This egg density is reduced according to
Figures 3 and 4 to give surviving adults. The fecundity of these adults is then determined as
a function of adult density, and the resulting total egg production is passed on to the dispersal
submodel. Note that these calculations do not make explicit use of forest stand condition;
effects such as starvation are represented implicitly through population density.

The dispersal calculations redistribute eggs between areas according to the distance relation-
ship in Figure 5. The multiple-flight aspect of dispersal was not considered important, and
females were not assumed to be good at finding the best forest stands within any area. Thus
it was assumed that a proportion of the eggs dispersed to any area are lost in unsuitable habitat,
equal to the proportion of the area that is not in balsam fir or spruce stands more than 12 years
old. Females from low density populations were assumed to lay 50% of their eggs in their home
stand, and this proportion was assumed to decrease at high population densities.

The forest dynamics submodel was also made quite simple, by assuming that the proportion
of land not in balsam fir stands is constant over time for each area. Balsam fir dynamics was
represented in terms of stand age composition (by 3 year age intervals) and foliage standing
crop by age class (Figure 6). A stress index was used to represent the cumulative effects of
defoliation: the index increases only during years of high defoliation; otherwise it decreases.
It was assumed that tree mortality (movement into first age class) increases with the defoliation
index such that five years of complete defoliation of new growth would result in about 80%
mortality.

The management submodel turned out to consist of a series of calculations inserted at various points in the other submodels. In terms of forest management, it was assumed that the proportion of land in balsam fir and the fir age composition could be arbitrarily altered for any area. The economic or technical feasibility of such alterations was not considered. In terms of insecticide management, dose-mortality relationships were developed for larvae and adults using the data of MacDonald in Morris (1963). It was recognized that a variety of spraying tactics can be followed (for example, spray only high hazard areas based on egg densities, or spray in bands across the province), so several tactical options were programmed into the model. Particularly in relation to larval spraying, it was necessary to recognize that spraying on one life history stage may alter subsequent survival, by moving densities along the functional relationships show in Figures 3-4.

RESULTS AND DISCUSSION

Results of the spruce budworm modelling exercise fall into two categories: predictions made by the simulation model, and impacts on the scientists involved in its development. Each of these will be discussed in turn.

Since the number of variables is so large, it would be impractical to present here the full results from even one simulation run; thus only egg density maps like Figure 1 will be presented to give a general feel for the predictions. A word of caution is necessary because these maps do not show the sometimes disastrous changes in forest condition.

Figure 7 shows the results of three simulation runs with different management tactics, beginning with 1967 egg densities and forest conditions. In the "no spraying" simulation, all insecticide application was stopped; the model predicted that this would result in a collapse of the outbreak after about 15 years, with virtually complete destruction of mature balsam fir stands across the province. Note that the simulated outbreak collapsed first in the center of the province (where it first appeared); this in fact has apparently occurred, and insecticide spraying in 1972 and 1973 has been concentrated in the northern and southern areas that the model predicted should become problems within five years. The second simulation in Figure 7 represents a spraying dose and spatial patterning of application approximating that which is currently used. Again the bimodal outbreak patterns appeared by year 5, as observed, but the model predicted that the outbreak should still subside in 15 years after much destruction of mature fir stands. The third simulation in Figure 7 is especially interesting; it represents a very high spraying dose in the spatial pattern currently used. In this case, the prediction was that the outbreak should be sustained indefinitely as a chronic problem, due to maintaining the balsam fir stands in mature condition. Concern that this prediction might be correct has been expressed by several scientists working on the budworm, but the published empirical evidence does not support our result, at least for DDT (see MacDonald in Morris, 1963).

As another general test of the model's predictive ability, we ran the "no spraying" simulation for sixty years. As shown in Figure 8, another outbreak appears after about 40 years (or about 50 years to 1967 levels). This period between outbreaks is in reasonable accord with historical evidence for New Brunswick. The suggestion is that we have probably captured in the model the basic factors that produce outbreaks: large areas of mature forest coupled with several years of good weather.

We believe that the budworm modelling exercise had considerable impact on the participants in the workshop. While attempting to carefully lay out the important components of the budworm-forest system and to provide data for the relationships between those components, three areas of research were revealed as requiring more emphasis than they were receiving. First, there are very few data available on the distance females fly and the proportion of eggs they

lay various distances from home areas. The simulated outbreak dynamics were sensitive to these factors. Second, there is need for data on the relation between tree stand characteristics and the tendency of females to oviposit. In the model we assumed that no site selection occurs, and this assumption leads to very high egg mortality estimates under many conditions. Third, budworm dynamics at low population sizes are not understood, and the possibilities for control during such periods may be great.

Still other subjects were placed in different perspective merely by having specialists from all aspects of the budworm program interact intensively. First, inconsistencies were revealed in the types of data gathered by the different disciplines involved in the project. For example, foresters have been gathering massive amounts of forest inventory data, largely descriptive in nature. These data must be useful for some aspects of forest management, but for predicting changes in the kinds of forest characteristics which are important to the budworm (such as tree recovery rates after given amounts of defoliation) these data proved almost useless. High priority was thus indicated for acquiring more dynamic forest data. A more subtle result arose from having different specialists use the goal of building a model as a focus for mutual exchange of ideas. Several people saw much more clearly how their particular area of research fit into the overall study, and some were forced to rethink the importance of the kinds of information they were gathering. It is worthwhile noting that much of this soul searching occurred before we even had a running simulation model.

Clearly the model described above is crude, oversimplified, and naive in most respects. We would not expect it to be directly usable as a management tool, but it should provide a frame of reference or starting point from which constructive criticism could eventually lead to a powerful predictive tool. There is good indication that this continued development will actually occur.

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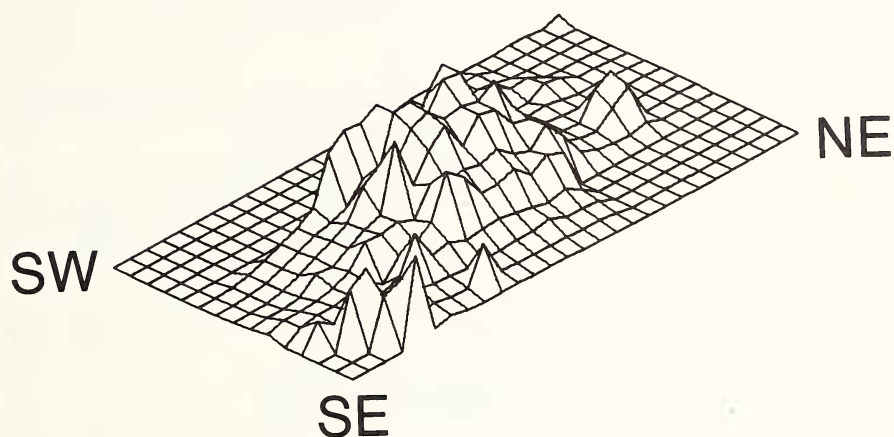
STARTING CONDITIONS
EGG DENSITIES

Fig. 1. Spruce budworm egg densities on a stylized map of New Brunswick in 1967. Each grid area is 6 x 9 mi, and map heights represent eggs/10 ft^2 of foliage (maximum ~1000/10 ft^2). All simulations were started from this condition.

Fig. 2. General flow of annual calculations in a simulation model of spruce budworm populations in New Brunswick.
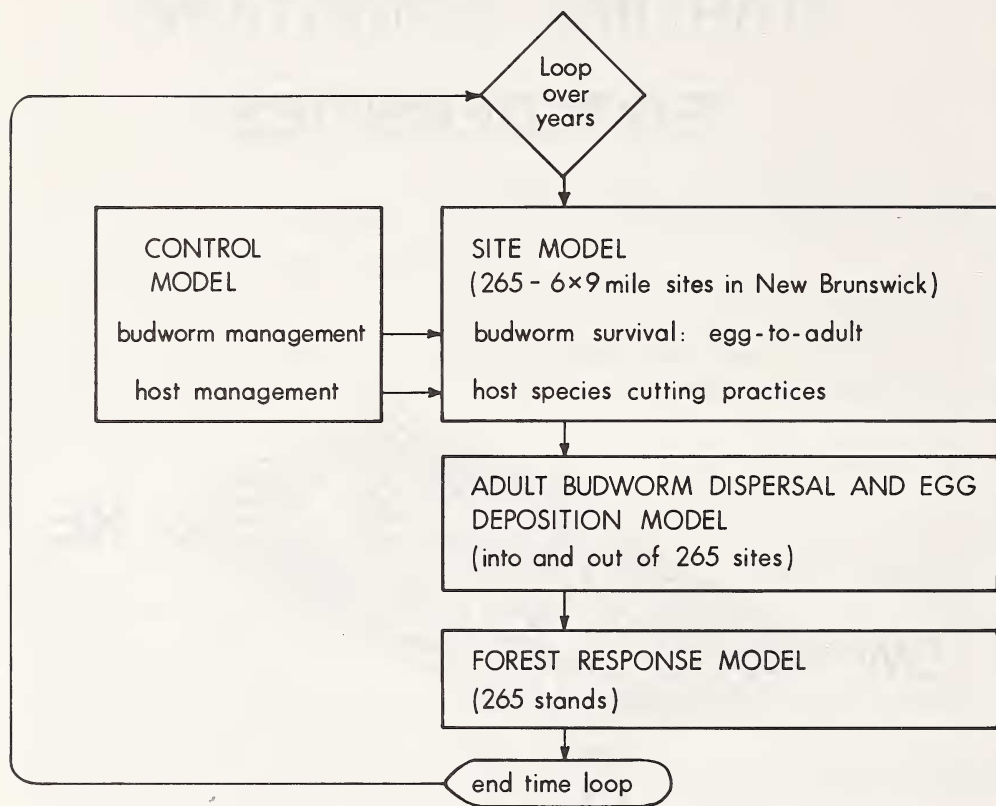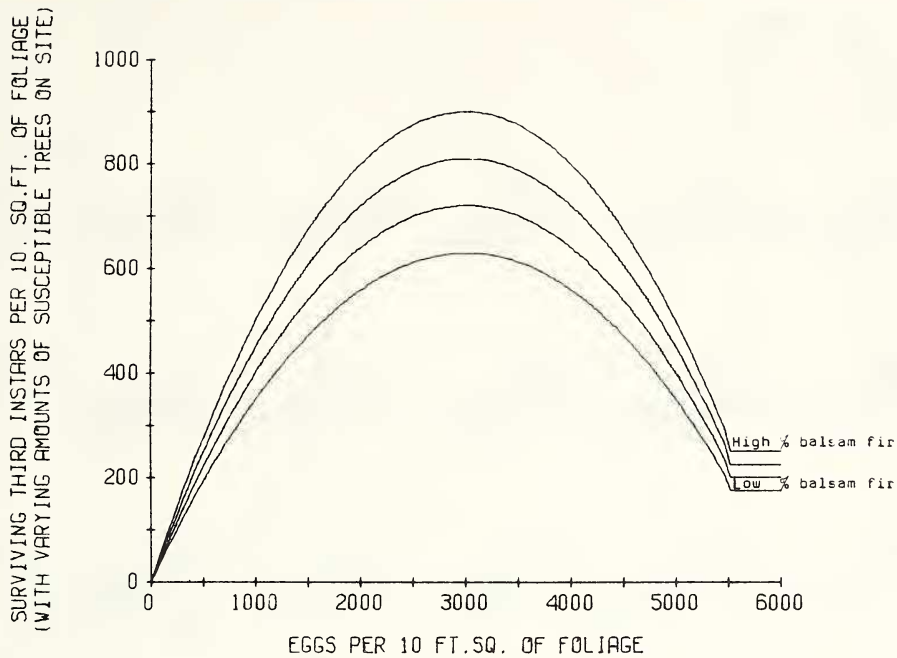
Fig. 3. Functional relationship between initial egg density on any area and resulting third instar larval density. Established by workshop participants from data in Morris (1963).
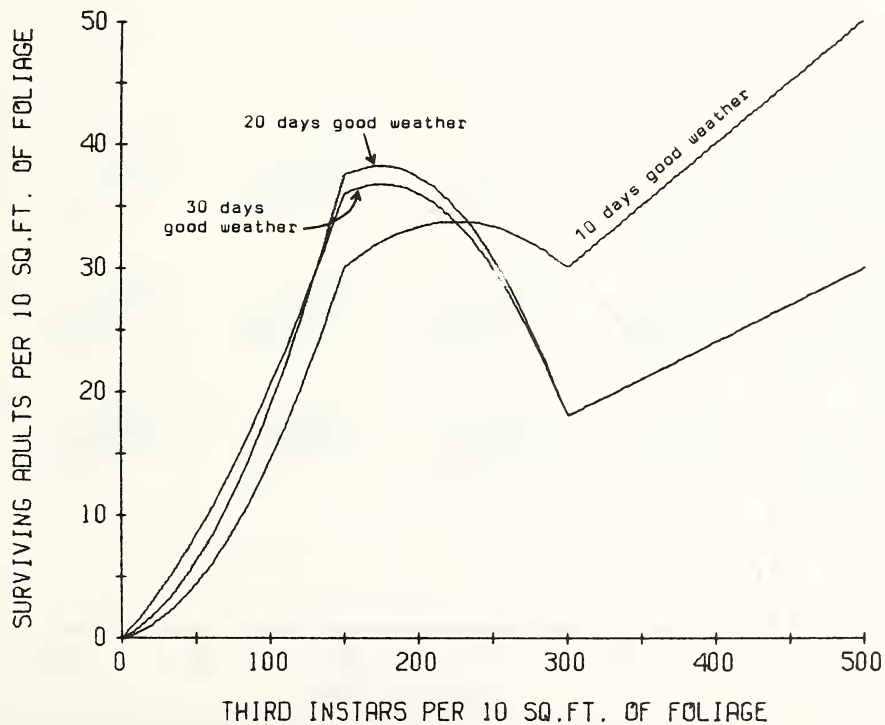

Fig. 4. Functional relationship between 3rd instar density and surviving adults. Established from data in Morris (1963).
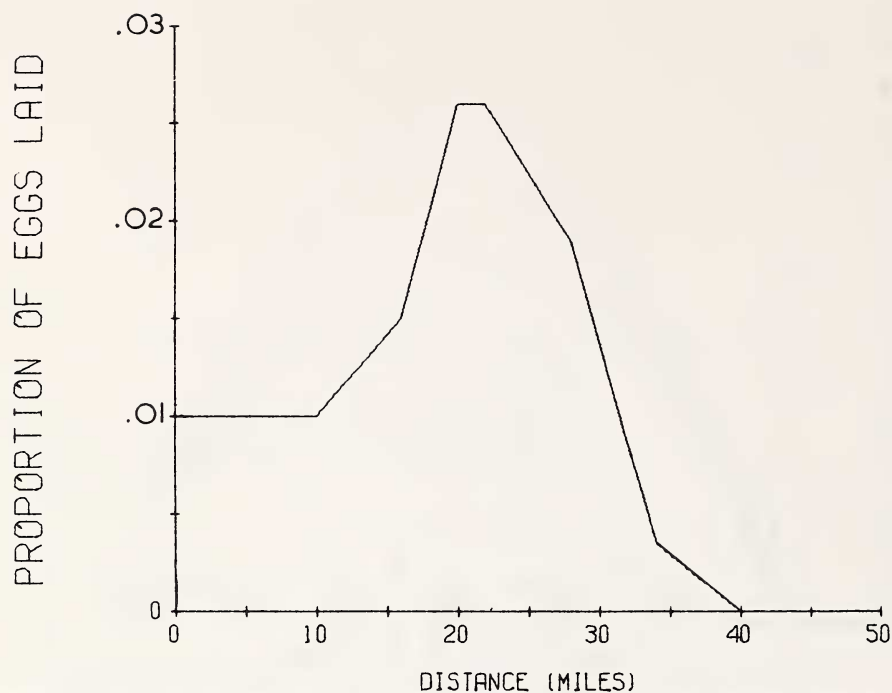
Fig. 5. Functional relationship for adult dispersal as a function of distance from home area. Established from data provided by Greenbank (pers. comm.).
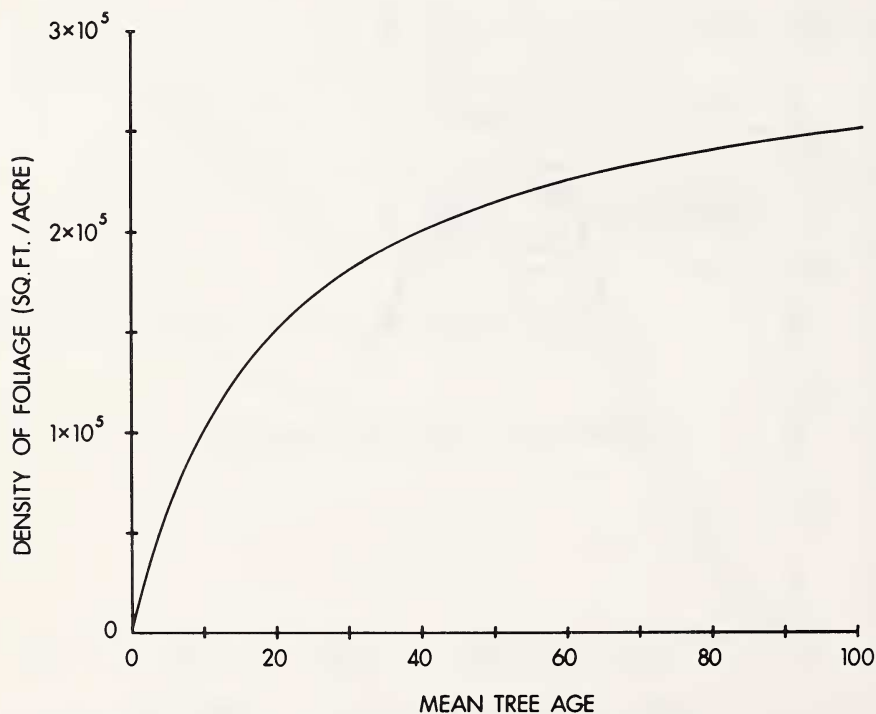

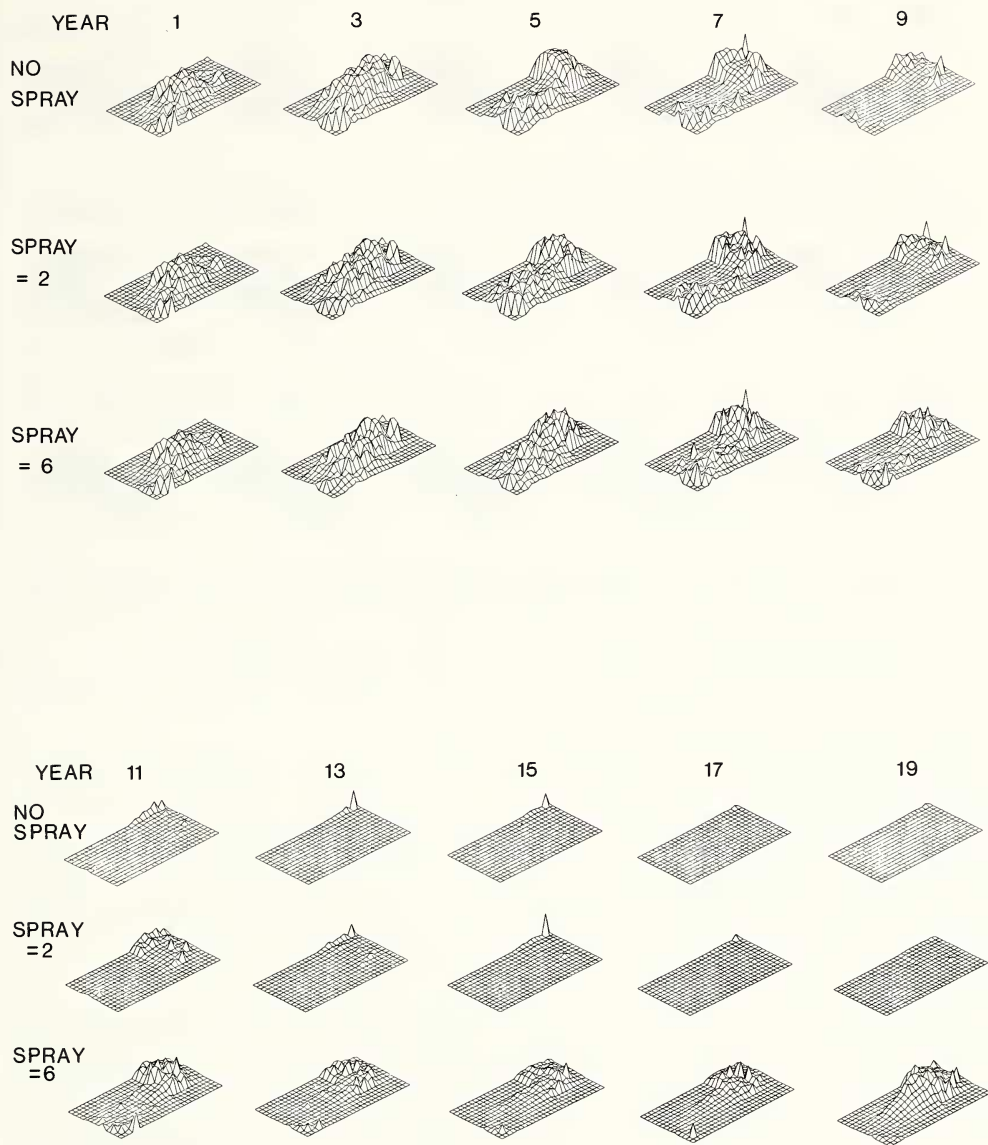Fig. 6. Functional relationship between maximum foliage density and stand age for balsam fir.

Fig. 7. Simulated budworm egg densities over New Brunswick for three alternative management tactics, beginning in 1967. Each map is as Figure 1; explanation of results in text.

NO SPRAYING

YEAR   40   41   42   43   44

YEAR   45   46   47   48   49

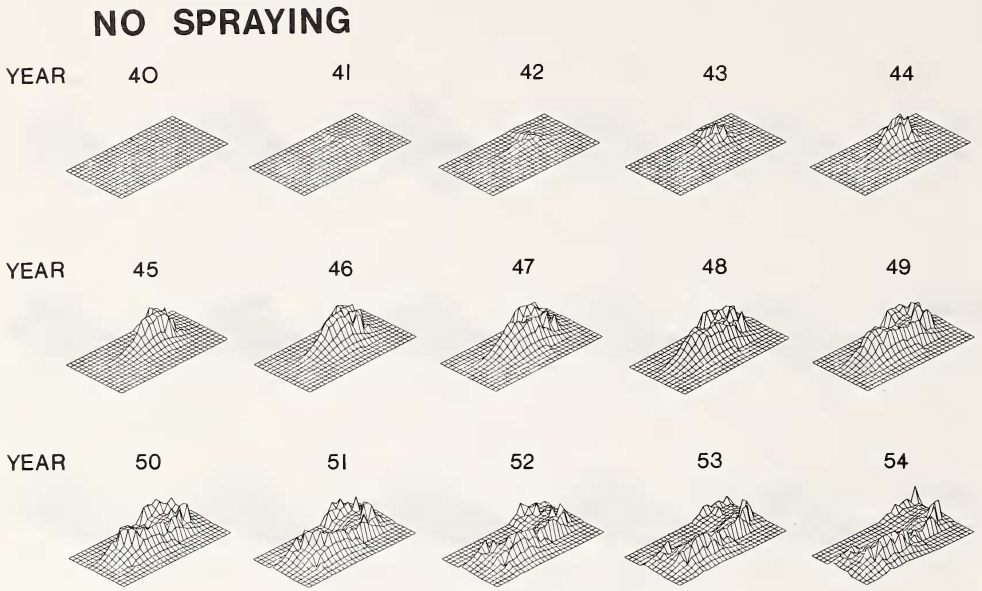YEAR   50   51   52   53   54

Fig. 8. Simulated appearance of a new outbreak after 40 years; generated by continuing the "no-spraying" case in Figure 7.